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Project DAMP

Progress Report

MEASUREMENT OF ATMOSPHERIC ATTENUATION

Aboard USAS AMERICAN MARINER

Prepared for
Army Ordnance Missile Command, Redstone Arsenal, Alabama
under Contract No. DA 19-020-ORD-5372
and
Advanced Research Projects Agency, Washington, D.C.
under Order 51-61

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March 12, 1962

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I. INTRODUCTION

In the course of the analysis of optical measurements obtained on reentry studies made from USAS AMERICAN MARINER, a knowledge of the atmospheric attenuation between the reentry event and the observer is necessary. This is required in order to reduce the radiant flux density at the recording instrument to the absolute value of radiant intensity at the target itself.

A large effort has been expended in the past to accurately determine the absorption and scattering properties of atmosphere. However, the greater majority of the experimental programs have been on horizontal paths over varying lengths and terrains. The problem of atmospheric effects on the observation of a reentry event entails a knowledge of the transmission of the entire atmosphere at different elevation angles and is hence almost identical to the atmospheric transmission problem faced by astronomers. To a very good approximation, the "effective" atmosphere may be said to exist up to 40,000 feet, since most of the water vapor, dust and haze lie below this altitude. As most of the optical events occur at altitudes greater than this, it may be said that all radiation traverses the entire "effective" atmosphere. This immediately allows the sun to be used as a source of radiation for transmission measurements. The problem ~~then is~~ was to measure the effect of elevation angle on the flux density incident at the observer.

The geometry of the measuring system is shown in Figure 1. The relation between air mass and elevation angle is expressed as

$$L = \frac{1}{\sin \epsilon} \quad \text{(air masses)}$$

where ϵ is the elevation angle from the earth's surface. The approximation assumes a planar atmosphere and is good down to elevation angles of 5 degrees or so. We are here not concerned with smaller elevation angles. The air mass at an angle of 90 degrees (overhead) is defined as air mass 1. Figure 2 shows the relation between air mass and path length* as a function of elevation angle.

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*Path length here is a somewhat artificial concept based on the fact that if the entire atmosphere were uniform and homogeneous at a pressure of one atmosphere, it would have a thickness of nine kilometers. Hence air mass 1 corresponds to 9 km of atmospheric path at one atmosphere (760mm Hg.) pressure.

II. INSTRUMENTATION

The transmissometer used in these measurements is a Barnes Model R-1S1 radiometer designed specifically to monitor radiation emitted by the sun. It consists of a radiometer head, tripod-mounted, and an output meter with connecting cables. Provision is made to record the output, butthis is not usually necessary. The head contains a filter wheel, iris diaphragm, optical system, detector, radiation reference source, chopper and preamplifier. Figure 3 is an interior view of the optical head.

Incoming radiation is collected by a cassegrain-type mirror telescope. Although it may be focussed from two feet to infinity, it has been preset for infinity. The detector is a thermistor bolometer with barium fluoride window, which transmits from the visible to about 12 μ. Target radiation is compared with a blackbody radiation reference cavity by means of a polished chopper which modulates at 150 cycles/sec. As the detector alternately senses the blackbody radiation and target radiation, its output is an ac signal, whose peak-to-peak value is proportional to the difference between target radiation and reference body radiation. The preamplifier amplifies the detector output signal to a suitable level for transmission to a vacuum tube voltmeter located in the level meter where it is indicated on a panel meter. The filter wheel, which is mounted in front of the iris controlled aperture, is operated by a rotary solenoid indexed to 12 equal steps so that

it rotates 30 degrees each time voltage is applied. The wheel contains eleven filters and one opaque segment uniformly spaced on the circumference. The spectral region covered by each filter is shown in Figure 4 superimposed on a typical atmospheric transmission curve. More detailed information regarding filter characteristics is given in the instrument instruction manual.*

The electronics chassis contains, in addition to the previously mentioned voltmeter, a temperature monitoring circuit, all power supplies and facilities for testing and calibrating.

Through the previously mentioned filters, solar radiation is measured at eleven predetermined wavelengths, each with a different bandwidth. The spectral region covered is between 0.5 μ and 14 μ, and bandwidth varys from 11 Å to 5 μ. Filter bandwidths grow wider as the wavelength increases. This is designed to keep approximately the same radiation level at the detector at all times. Because the sun has a spectral distribution characteristic of a blackbody at approximately 5800° K, the radiation intensity declines continuously beyond 0.6 μ. This condition has been only partially achieved, since compromises in the filter characteristics were necessary in order to obtain stable and practical filters.

Figure 4 is a composite graph of filter response,

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*Instruction Manual for Transmissometer, Model R-181, BEC 4235-4 (Sept. 1961)

spectral location and bandwidth. It has been superimposed on a curve of atmospheric transmission as a function of wavelength for a typical maritime atmosphere measured over a 10-mile path at sea level. From this illustration, it may be observed that the filters have been so chosen as to take advantage of those regions of the spectrum which are essentially free from selective absorbers. These regions, or "windows" are in most cases fairly sharply defined areas between the major absorption bands of water vapor and carbon dioxide. One exception is filter No. 10. It is positioned in a window which has no area entirely free from water vapor absorption and has therefore been positioned at the edge of the window to evaluate the influence of water vapor absorption.

III. SOLAR MEASUREMENTS

The detector output for each filter wavelength is plotted against air mass as shown in Figure 5. The resultant curve is extrapolated beyond air mass 1 to a point which would correspond to an air mass of zero; i.e., no air and hence no absorption between source and observer. The transmission is therefore the ratio of the value of the deflection actually measured at a given elevation angle to the deflection at zero air mass.

Figure 5 is an idealized representation showing results from an infinitely clear atmosphere in the upper curve and results to be expected from a real atmosphere in the lower curve. The dip at air mass 3 is such as would result from a sharply defined cloud in an otherwise cloudless sky.

Data from each selected filter was recorded from the voltmeter deflection of the radiometer. For each set of filter readings, the sun's elevation angle was measured with a sextant before and after the readings. An average value of sun elevation was translated to air mass value by use of the graph shown in Figure 2.

A graph for each filter of deflection as a function of air mass was prepared for each day's readings. An average curve was drawn for each day and extrapolated to intersect the zero air mass ordinate. Typical curves are shown in Figures 6, 7 and 8 where four days' readings have been plotted.

An average deflection for zero air mass was calculated

from the zero air mass values shown. This average value is considered to be the 100 per cent transmission value for that particular set of data.

For the four days shown in these figures, the range of atmospheric conditions are here noted:

July 20 - ambient temperature 91° - 98° F
relative humidity 63% - 68%
cloud cover zero to 90%
cloud type - strato-cumulus and cumulus

July 25 - ambient temperature 83° - 90° F
relative humidity 64% - 77%
cloud cover 15% - 30%
cloud type - strato-cumulus

July 27 - ambient temperature 80° - 91° F
relative humidity 71% - 80%
cloud cover 5% - 15%
cloud type - cumulus and strato-cumulus

July 28 - ambient temperature 78° - 88° F
relative humidity 66% - 77%
cloud cover zero to 15% after midmorning when heavy rain had cleared
cloud type - strato-cumulus

In most instances, no data were recorded through cloud cover. However, one or two readings will be noted on the data presented, which shows probable severe attenuation due to a cloud.

For comparison purposes, an exponential curve of air mass versus deflection has been calculated and is shown for the three selected filtered regions in Figures 6, 7 and 8. For calculation of this curve, the extrapolated value for zero air mass and the value for 5.75 air mass were used. This exponential curve is in good agreement with the recorded data.

IV. TYPICAL ATMOSPHERIC TRANSMISSION

Figure 9 shows the results from two filters (B and I at wavelengths 0.6 μ and 3.24 μ respectively) for a given day plotted as transmission (obtained by dividing each deflection value by the extrapolated intercept point for zero air mass) as a function of air mass and elevation angle. The fit to a purely exponential curve (put through the zero air mass point and 5.8 air mass point) is quite good and the attenuation at 0.6 μ is observed to be more pronounced than at 3.24 μ.

Figure 10 shows typical transmission values for each filter as a function of elevation angle and wavelength. The upper curve shows values for an elevation angle of 70°, the center curve is at an elevation of 50° and the lower curve at 30°.

For this particular set of measurements, the range in transmission between the low and high elevation angles is about 8 per cent at 2.28 μ and about 20 per cent at 0.49 μ. This illustrates the anticipated result that scattering accounts for a high percentage of transmission loss at the shorter wavelengths.

V. SUMMARY

To achieve the best transmission values for a given set of reentry data, it is necessary to make solar measurements before and after the event (since most reentries occur during darkness). By making use of the average zero air mass value, a per cent transmission may be calculated from data taken the afternoon before and the morning after a test for the particular wavelength region measured, and for the particular elevation angle of the observed target. Hopefully, the transmission values measured in this way can safely be extrapolated to the time at which reentry actually occurs.

By the compilation of extensive data in the nominal reentry area, an atmospheric model is under development ~~being developed~~ which will permit, in the absence of specific measurements, correction for atmospheric attenuation to an expected accuracy of + or - 20% ~~per cent~~.

To summarize the findings in this initial study:

1. Attenuation by scattering varies over a wide range with the geographic location and the local atmosphere as anticipated.

2. Transmissometer measurements of sun radiation will yield useful atmospheric transmission values for application to reentry measurements.

3. The exponential form of a plot of transmission versus air mass holds for most results, making it possible to apply these atmospheric correction factors even though weather conditions permit only a few isolated points of data.

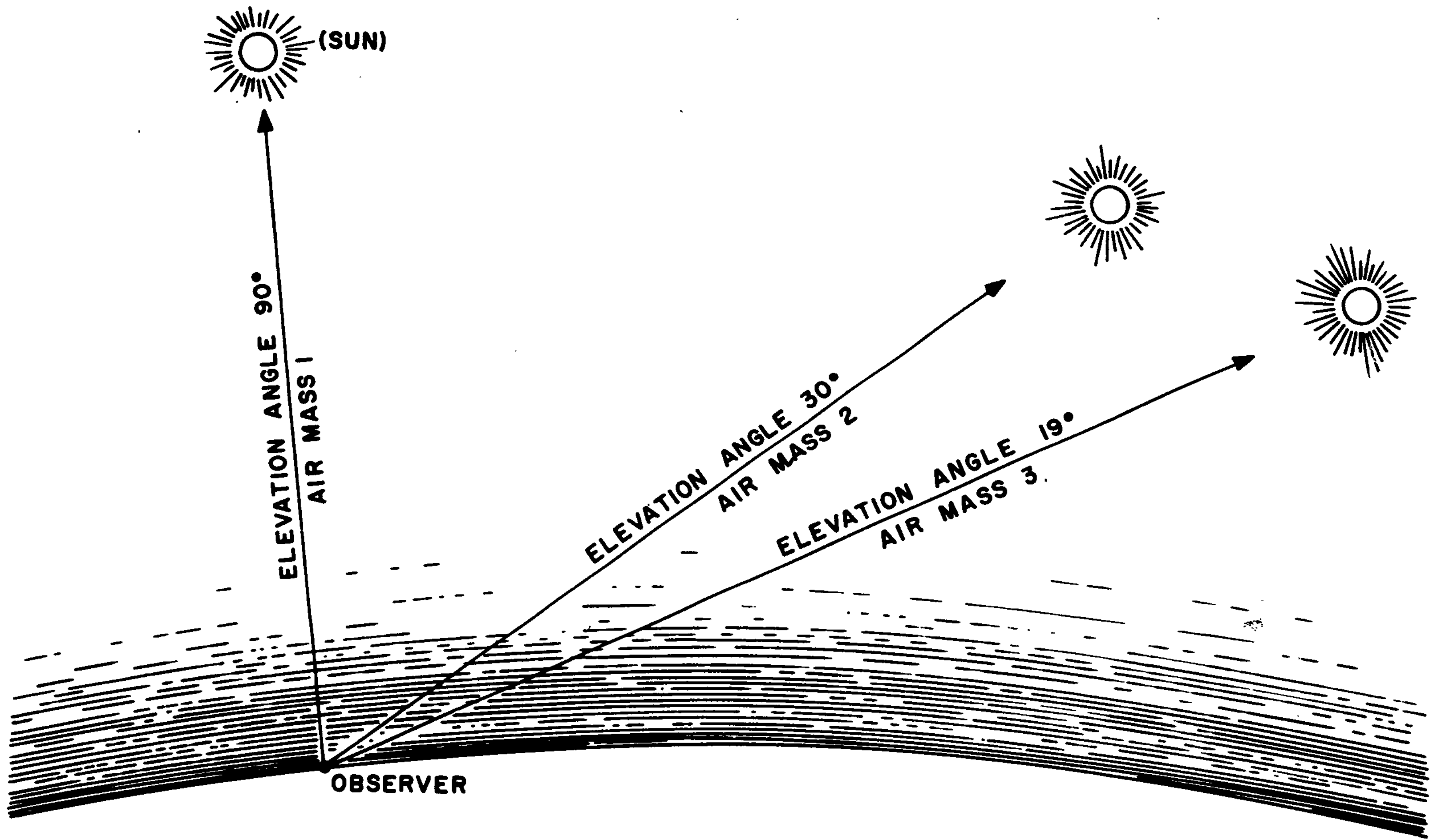

Figure 1
RELATIONSHIP OF OBSERVER AND ATMOSPHERE FOR TRANSMISSION MEASUREMENTS BY SOLAR OBSERVATIONS

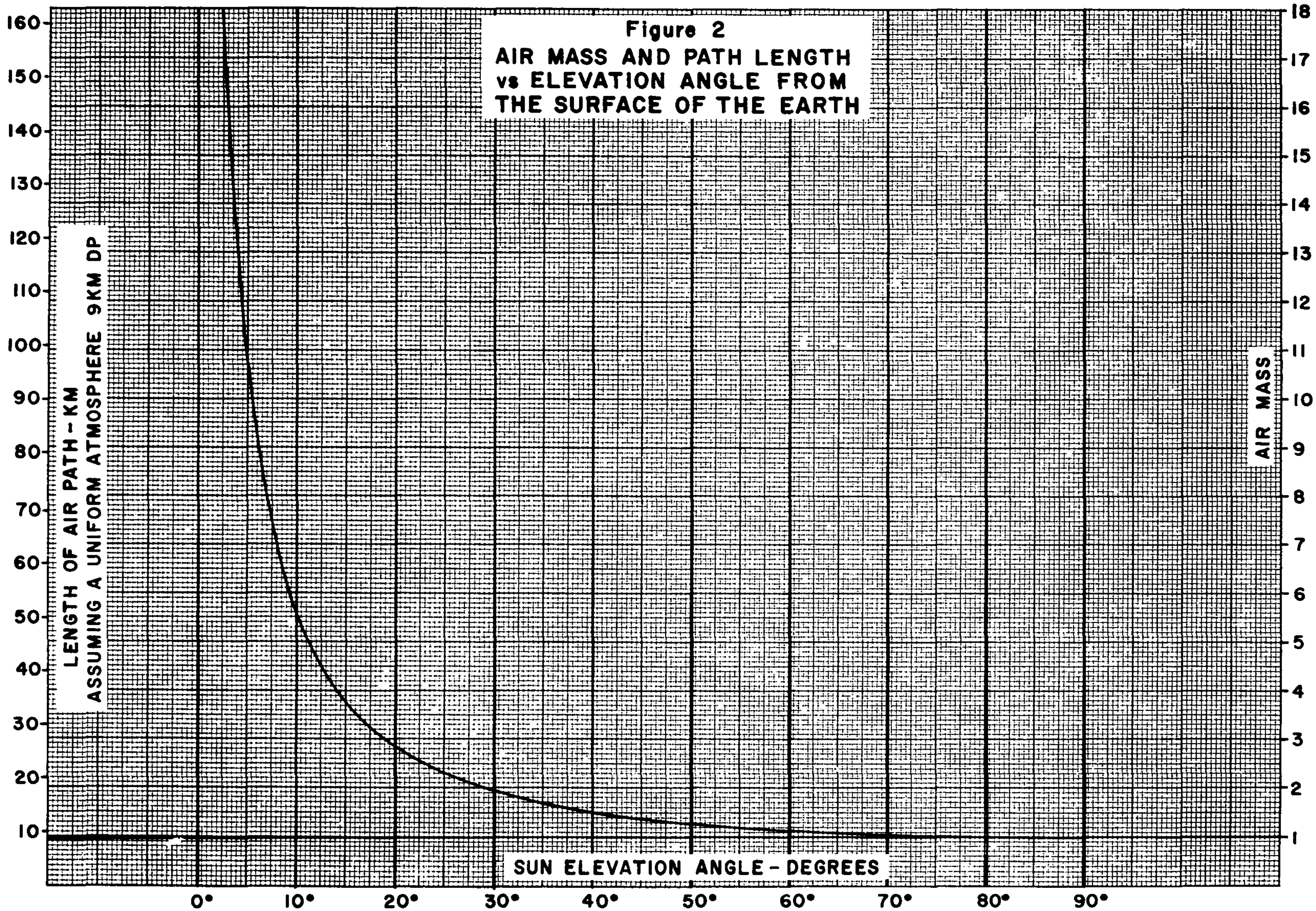

Figure 2
AIR MASS AND PATH LENGTH
vs ELEVATION ANGLE FROM
THE SURFACE OF THE EARTH

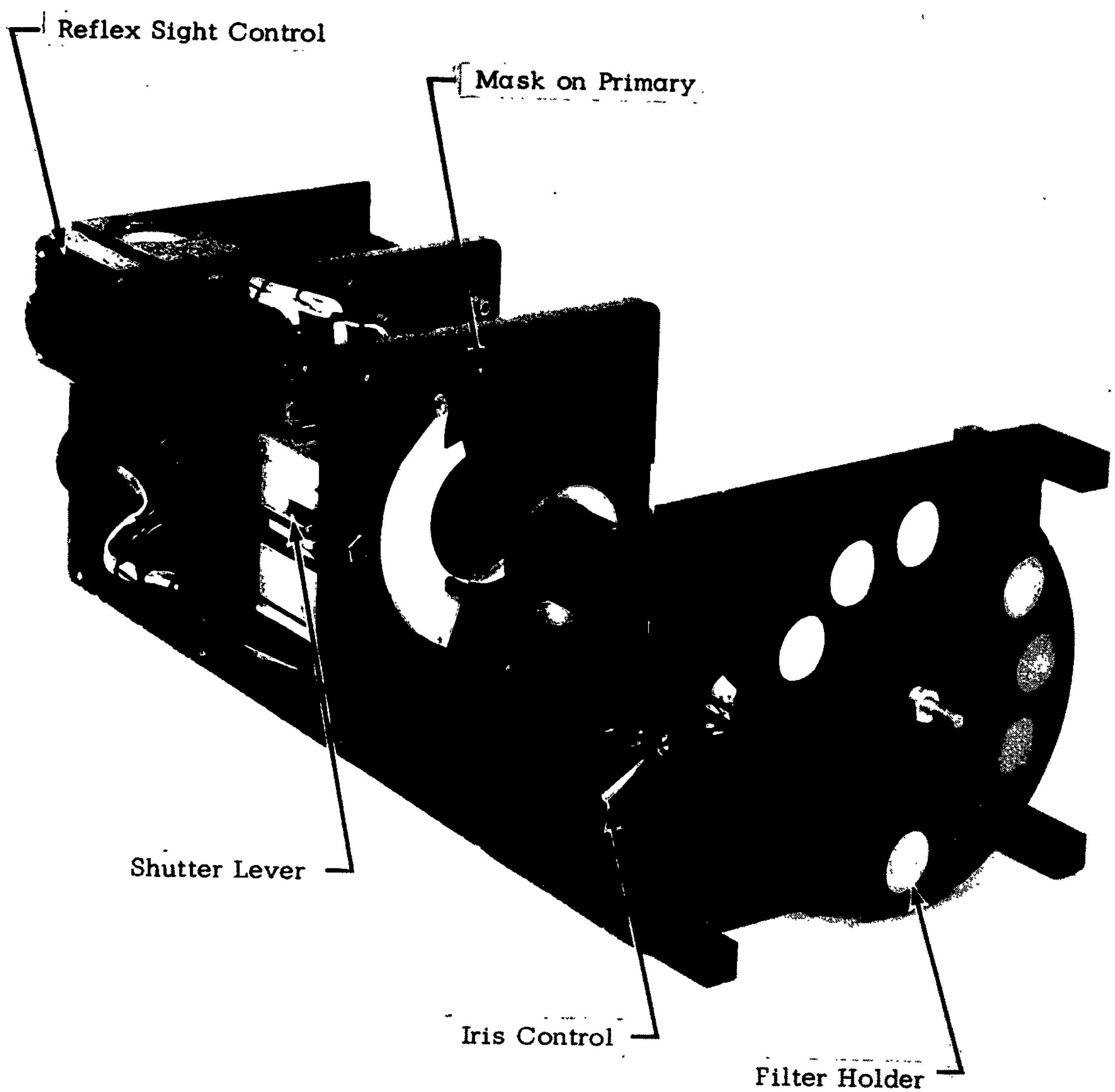

Figure 3 OPTICAL HEAD, LEFT SIDE INTERIOR VIEW

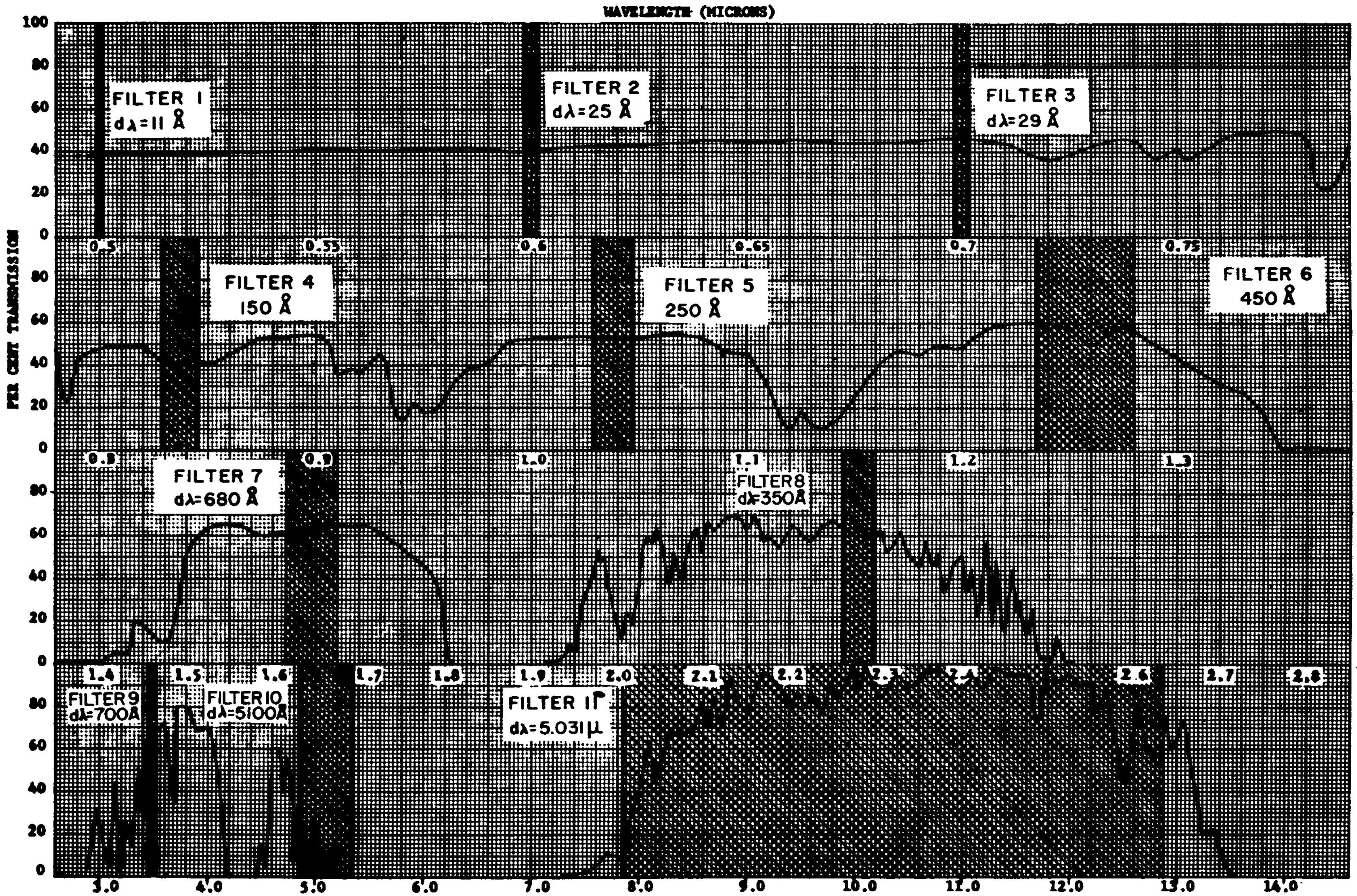

Figure 4 - OVERALL FILTER TRANSMISSION RESPONSE CURVE

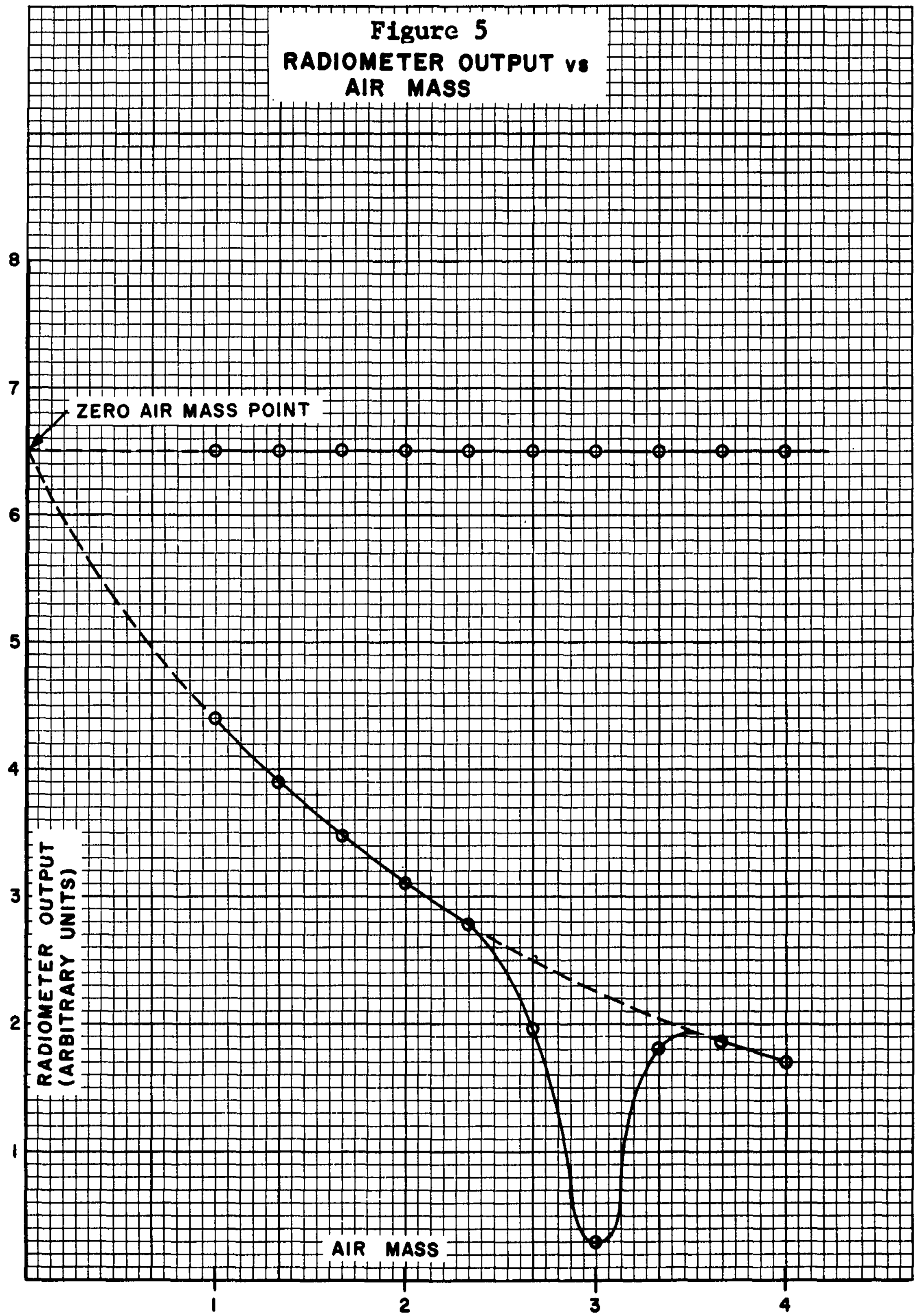
Figure 5
RADIOMETER OUTPUT vs
AIR MASS
ZERO AIR MASS POINT
RADIOMETER OUTPUT
(ARBITRARY UNITS)
AIR MASS
1
2
3
4
5
6
7
8
1
2
3
4

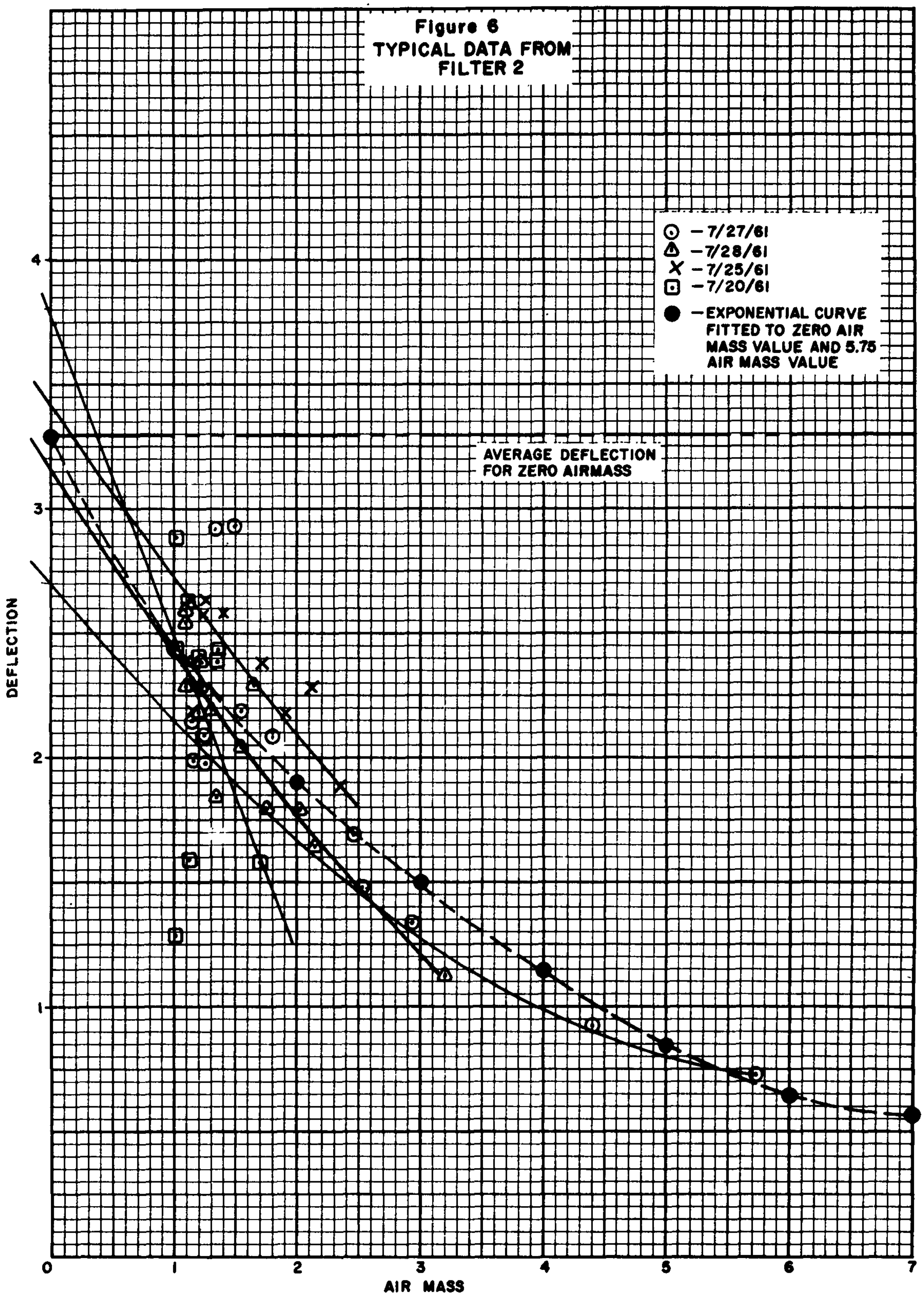
Figure 6
TYPICAL DATA FROM
FILTER 2
⊙ – 7/27/61
△ – 7/28/61
X – 7/25/61
⊡ – 7/20/61
● – EXPONENTIAL CURVE FITTED TO ZERO AIR MASS VALUE AND 5.75 AIR MASS VALUE
AVERAGE DEFLECTION FOR ZERO AIRMASS
DEFLECTION
AIR MASS
0
1
2
3
4
5
6
7

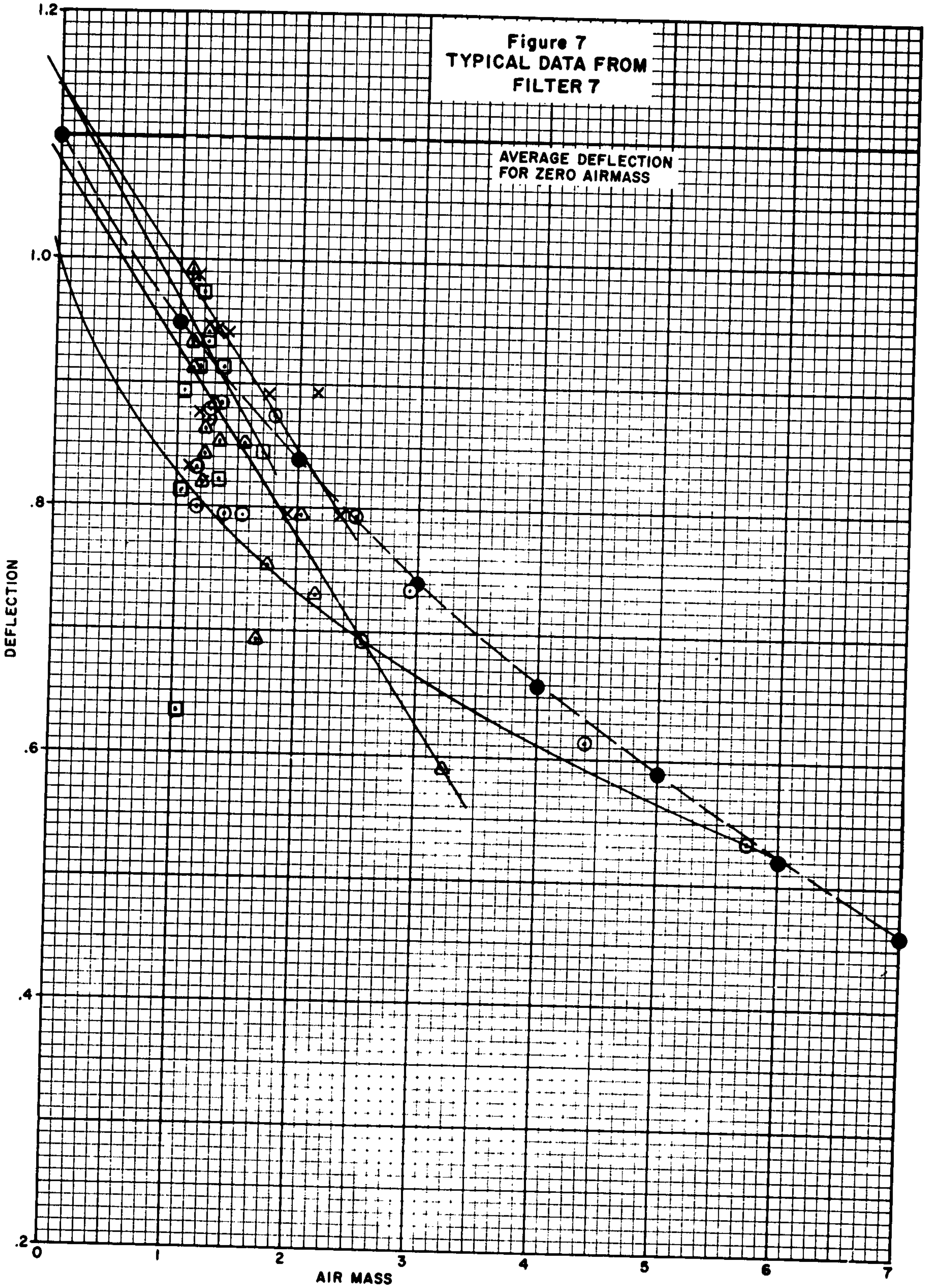
Figure 7
TYPICAL DATA FROM
FILTER 7
AVERAGE DEFLECTION
FOR ZERO AIRMASS
DEFLECTION
AIR MASS
1.2
1.0
.8
.6
.4
.2
0
1
2
3
4
5
6
7

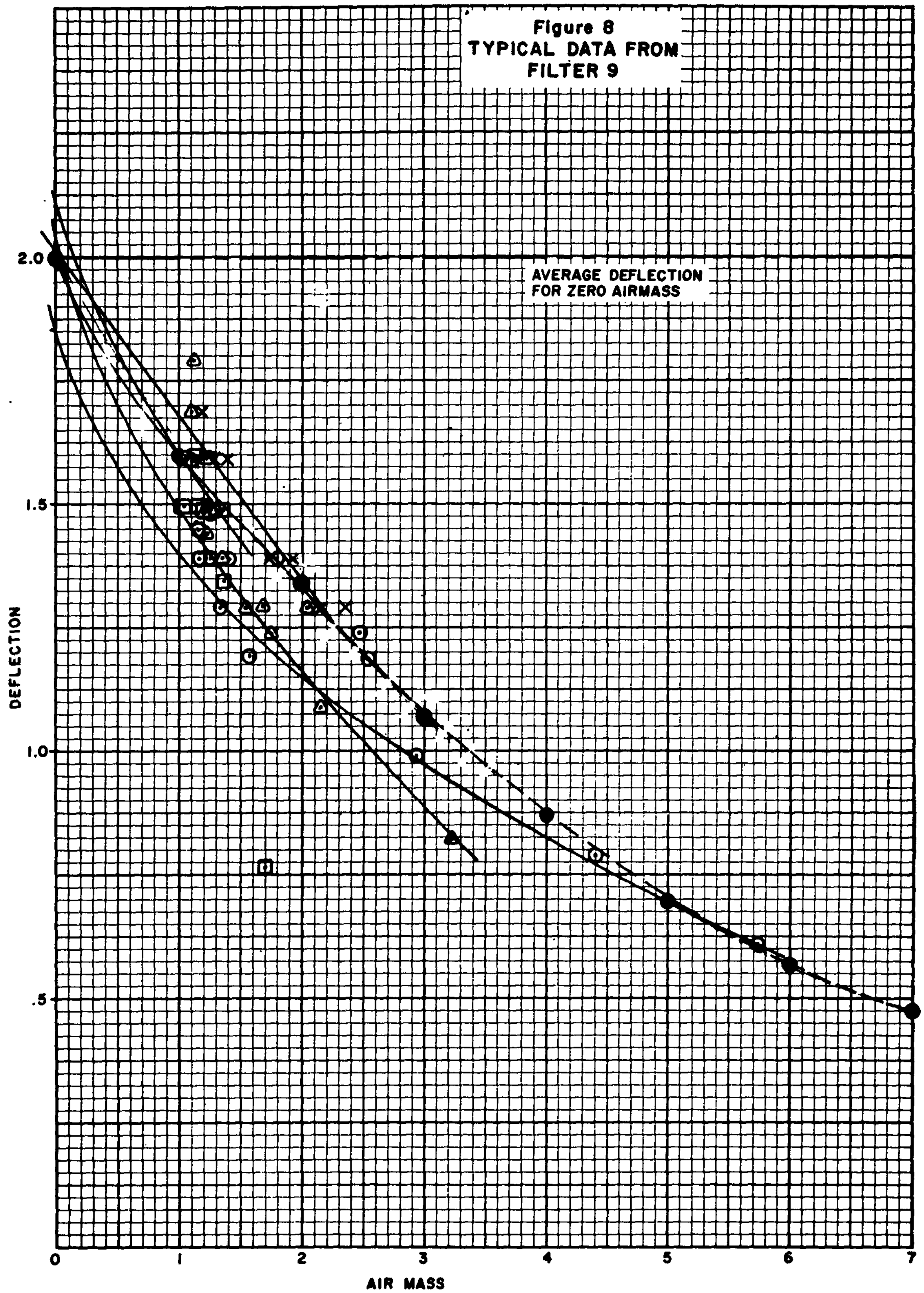
Figure 8
TYPICAL DATA FROM
FILTER 9
AVERAGE DEFLECTION
FOR ZERO AIRMASS
DEFLECTION
2.0
1.5
1.0
.5
0
1
2
3
4
5
6
7
AIR MASS

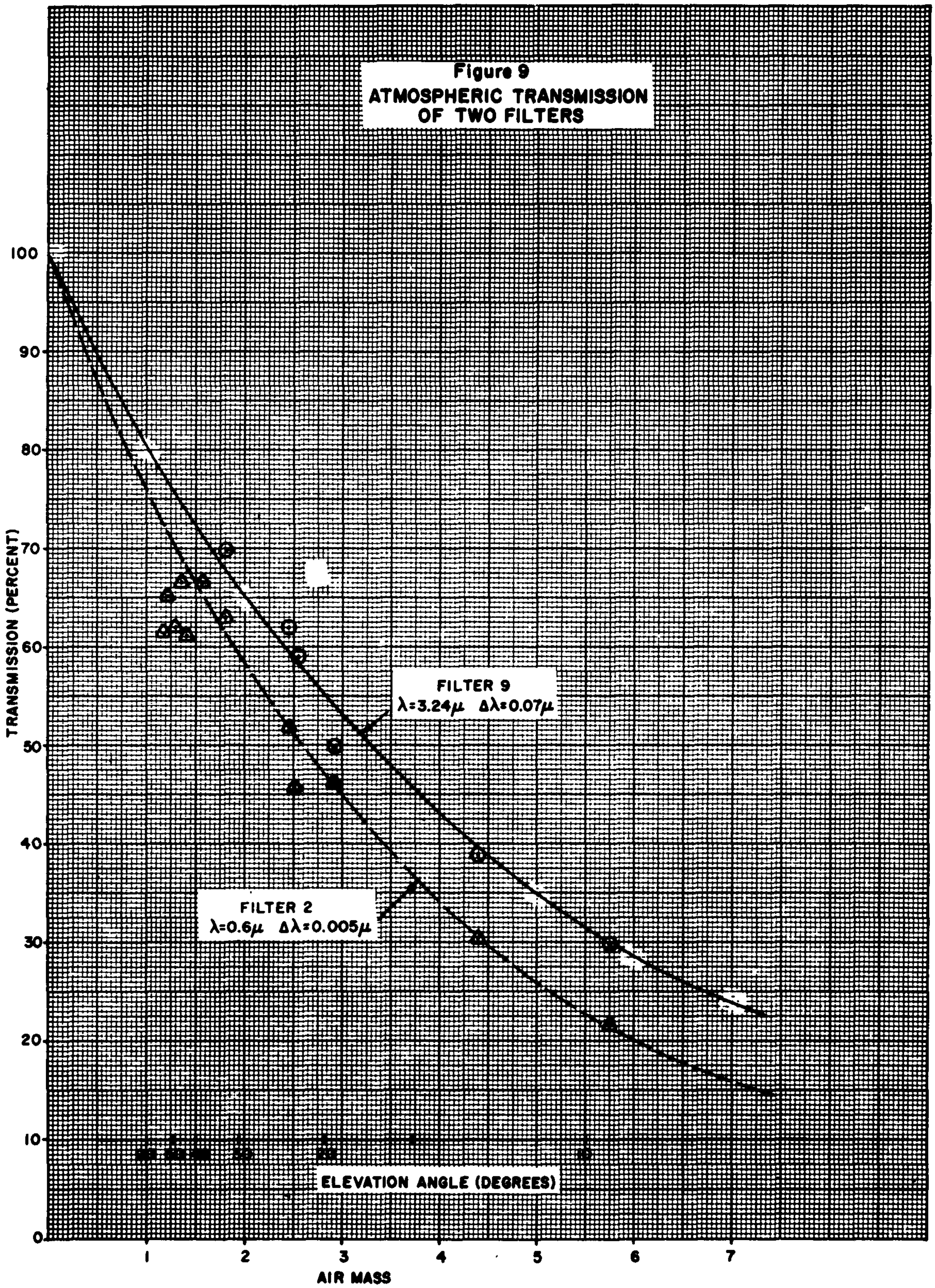

Figure 9
ATMOSPHERIC TRANSMISSION OF TWO FILTERS

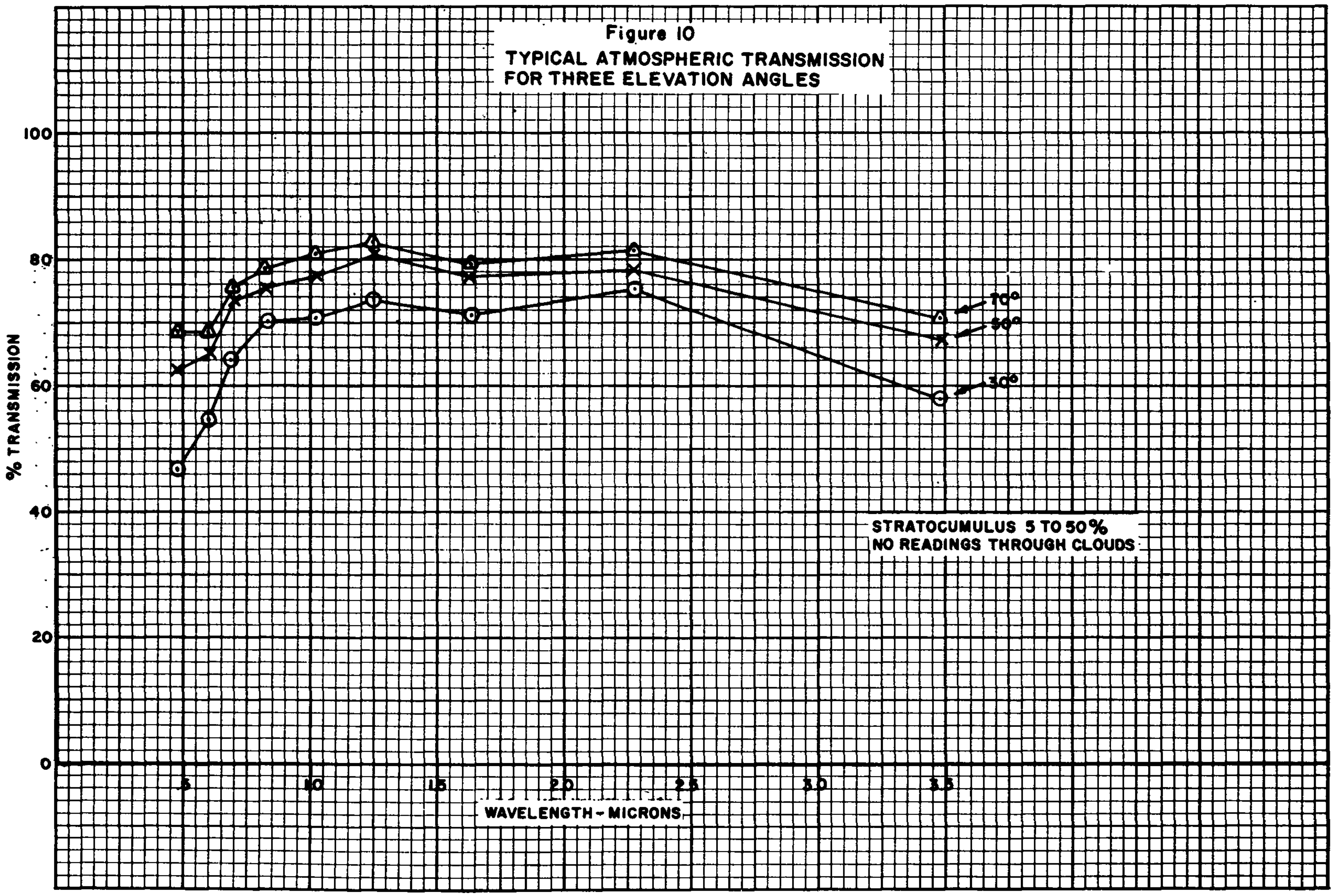

Figure 10
TYPICAL ATMOSPHERIC TRANSMISSION
FOR THREE ELEVATION ANGLES
100
80
60
40
20
0
% TRANSMISSION
.5
1.0
1.5
2.0
2.5
3.0
3.5
WAVELENGTH - MICRONS
70°
50°
30°
STRATOCUMULUS 5 TO 50%
NO READINGS THROUGH CLOUDS